# Art. VIIL.-Experimental Eiror of Field Trials in Australiu. 

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## Introduction.

The question of the "Probable Error" in field trials is one which has in recent years come to the fore in connection with the work of experimental stations in Europe and America. It has sometimes been suggested that in Australia the water supply available in the soil for the crop is often the limiting factor to growth and seed production. This might lead to a more uniform growth, and thus the experimental error of plot observations might be thereby diminished. It seemed, therefore, worth while to investigate the matter fully, and with this end in view the classic experment of Hall and Mercer was repeated at the State Research Farm, Werribec, Victoria, it being felt that such an investigation should lead to valuable results which would be a guide for the future in the " lay out " of the trial plots.

The experiment was undertaken to determine-
(1) the variation in an apparently uniform acre of wheat as measured by the " Standard Deviation," and the " Probable Error " of $1 / 160$ th acre plots,
(2) the optimum
(d) size,
(b) shape,
(c) number of plots necessary to reduce this error to a minimum.

## Method.

During the season 1926-27, the North Railway Field at Werribee was planted with " Free Gallipoli" wheat, and it produced a fair average crop, which was, before harvest. expected to yield about 24 bushels to the acre. An acre of this was selected for the experiment, and many casual observers were agreed that as far as the cye could judge, it was an even area of wheat.

A preliminary survey was made on the 29th November, 1926, when it was observed that the drilling was somewhat irregular. There was one double-sown row in every stroke of the drill, and therefore it was decided to include two of these double-sown rows in each plot. Accordingly each plot was made $30 \times 20$ links, and the dimensions of the whole acre, $300 \times 320$ links, excluding
paths. Further it was found that near the western boundary of the acre, a strip a few yards wide had been damaged by carttracks. This was consequently excluded.`

A straight row on the western side of the acre was taken as a base-line, and from this all measurements were set off. These allowed for the division of the acre into four quarters by means of two intersecting paths.

On account of the dianger of shaking-ont by storms before the harvesting of the whole area had heen completed, an occurrence which would have wrecked the whole experiment, it was deemed advisable to mark out only one quarter-acre at a time. This was then harvested immediately. Owing to extremely favourable weather conditions during the harvesting period. such precautions proved unnecessary.

Along the boundaries of each quarter-acre pegs were put in corresponding to the corners of the outside plots. The boundaries of each $1 / 160$ th acre plot were then defined by stakes whose positions were obtained by sighting from the outside pegs. Paths were then cut in a $\mathbb{N}$-S. direction, dividing the quarter-acre into 5 strips of 8 plots each. These paths were 4 drill-rows wide, and were made by hand-cutting 2 rows on each side of the actual houndaries of the plot as defined by line and plimb-bob. As the bags for the reception of the produce from each plot had previously been marked, the crop cut in the formation of the paths was transferred immediately to the corresponding sack.

Cutting was commenced on the 22nd December with a singlehorse mower fitted with a carrier-arrangenent. The mower was driven in an E.-W. direction across the paths, thus cutting five plots. It was stopped in each pathway-specially cut for this pur-pose-to enable the crop cut from each plot to be bagged straight from the carrier. After four swathes of the mower, a strip of about one foot was left along the northern boundary of each plot. This was cut by hand, the exact boundary being defined by line and plumb-bob as before. Plots were then thoroughly gleaned for any heads that had been broken off, as well as any loose straws.

Before cutting, the plots were examined for the number of rows they contained, and for the presence of any disturbing factors. There were very few weeds. In a similar mamer the other three quarter-aeres were harvested, the bagged produce of the plots being carted and stored as the harvesting of eich quarteracre was completed. Field work was finished on the 7th January, 1927.

Thrashing was commenced on the 18 th January. This was performed hy means of a motor-stripper, which consisted of the drum and beaters of a typical Australian harvester, driven by a stationery engine mounted on the same under-carriage. After thrashing the wheat fed into the beaters, both straw and grain were delivered into a bin at the rear. Here the straw was collected, and later re-thrashed separately from the grain. The
grain was winnowed to an even sample, and weighed to the nearest ounce, which was considered the limit of the overall accuracy of the experiment. Thrashing was completed on the 27th January.

## Results and Discussion.

Table 1.-Plan and zeeights in ounces of grain harecsted from 160 rilleat plots.


Table 1 shows the yields of plots together with their position in the field. The yields varied from 108 to 164 ozs., the variation being $20.6 \%$ on either side of the mean. The frequency curve as shown in Figure 1 was obtained by grouping the yields into periods of 5 ounces each.

With the curve from the actual results is shown the normal curve of ertor calculated to fit the results. Owing to the small number of observations, the approximation of the actual curve (vide Figure 1) to the above is considered close enough to justify the conclusion that the material was homogeneous, and that the formulae applicable to such, may be used in this case.

A study of Table 1 shows that there is a definite rise in yield from East to West, while the variations from North to South are apparently irregular. The graph (Fig. 2) of the sum totals of the rows of plots, as set out in Table 2, verifies these conclusions.


Fig. 1.-Firequency curves for 130 zehent plots. (Actual and Theoretical).

It is necessary to consider briefly these disturbing elements before proceeding to the main discussion and conclusions.

The presence of such a regular rise in the field under observation is a factor which has appeared in most investigations of this character. In their Mangold experiment, Hall and Mercer had a similar experience in a variation from North to South of $7 \cdot 3 \%$, which, after being observed and noted, was subsequently disregarded in the calculation of results. In this case, there is a variation from E.-W. of $6.9 \%$ on either side of the mean. The irregular variation from South to North is similarly $5.9 \%$. Since

Table 2-I'apling wevight of rozes of plot yields.

| Solth-North | East-West |
| :---: | :---: |
| $14140 \mathrm{cs}$. | $20: 30 \mathrm{Ozs}$ |
| $110: 3$, | 2035 |
| 135.4 , | $\because 102$ |
| 1370 | 2121 : |
| 1360 ," | 2138 |
| 1330 , | 2231 |
| 1342- | 2254 |
| 1:345 ", | 2264 , |
| 1312 , | 2237 |
| 1331 " | 23:3:3 |
| 1312 . |  |
| 1345 |  |
| 1317 - |  |
| 1339 , |  |
| 135: |  |
| 1771 , |  |

these variations, viz. 69 from E.-W., and $59 \%$ from S. N., are of approximately the same order, it is possible in a similar manner to disregard this regular variation from side to side.


Fig. 2.- Tlarying weights of rows of piot yields.

Hall and Mercer in their experiment measured each plot as a definite distance along a certain number of rows, thus taking area of crop as their unit. On account of the irregular drilling, it was impossible in this experiment to include a definite number of rows in each plot; therefore area of land was taken as the unit.

The examination of the number of drill rows showed a variation of from 33 to 35 rows per plot. This variation, $34 \pm 1$, is of the order of $3 \%$. On taking only those plots containing 34 rows, the yiclds varied from 115 to 164 ounces, a range of approximately $18 \%$ on cither side of the mean. Thus the normal variation due to chance is far greater than the difference that could be produced by such variation in the number of rows, and this may therefore be grouped with these chance errors. A more accurate comparison may be drawn between the Standard Deviation of all the plots (S.D. $=10 \cdot 9 \pm 0 \cdot 41 \mathrm{ozs}$.), and that from those containing the same number of rows (34), S.D. $=11.9 \pm 0.58$ ozs.). These two figures are of the same order. Now, since this S.D. is a measure of the variance of the plut yields, the above assumption is confirmed.

The Variation in an Apparently Uniform Acre of Wheat as measured by the Standard Deviation and the Probable Erpor of $1 / 160$ th acre plots.

Table 3.-Calculation of the Standard Deviation.

| Group | Frequency |  | Deviation from <br> Arbitrary Mean |  |  | $\mathrm{x}^{2}$ |  | fx |  | fx ${ }^{2}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | f |  | $x$ |  |  |  |  |  |  |
| j07-111 | - | 2 | - | $-5$ | - | 2.) | - | -10 | - | 50 |
| 112-116 | - | 1 | - | -3. | - | 16 | - | -t | - | 16 |
| 117.12t | - | 12 | - | -3 | - | 9 | - | -36 | - | 108 |
| 122-126 | - | 18 | - | -2 | - | 1 | - | -36 | - | 72 |
| 127-131 | - | 18 | - | -1 | - | 1 | - | -18 | - | 18 |
| 132-136 | - | 32 | - | 0 | - | 0 | - | 0 | - | 0 |
| 137-14.1 | - | 29 | - | 1 | - | 1 | - | 29 | - | 29 |
| 14:-146 | - | 21 | - | 2 | - | $\pm$ | - | 48 | - | 96 |
| 147.151 | - | 11 | - | 3 | - | $!$ | - | 33 | - | 99 |
| 152-156 | - | T | - | 4 | . | 16 | - | 28 | - | 112 |
| 157-161 | - | 5 | - | 5 | - | 25 | - | 25 | - | 125 |
| $162-166$ | - | 1 | - | 6 | - | 36 | - | © | - | 36 |
| 'J'otals. |  | 160 |  | - |  | - |  | 65 |  | 761 |

It may be calculated by the usual formulac that the mean yield of the $1 / 160$ th acre plots is $136.5 \pm 7 \cdot 3$ uzs., i.e., there is an even chance that the yield from any one plot will be between 143.8 ozs.
and 1292 ozs. Further that if a comparison were made between a pair of $1 / 160$ th acre plots of two different varieties of wheat on similar land to that found here, any differences between yields of less than 23.3 ozs. ( $17.7 \%$ of the mean), would not be significant.

## Optimum Size of Plot.

In order to determine the optimum size of plot for purposes of yield trials, i.e. that size of plot which will give the least variation from the mean, it was necessary to compare the S.D. of different sizes of plots. By the grouping of adjacent plots, the yields from areas of different sizes have been obtained. The method of grouping is indicated by the accompanying dimensions in Table 3.

Table 4.-The Standard Deviation (\%) of Plots of Various Sizes.

N.B.-The small number of results in the two latter cases detracts somewhat from the reliability of the figures 5.2 and $4.6 \%$ respectively.

From the above table and the following graph, it will be noted that the S.D. (\%) falls rapidly from $8.0 \%$ in the case of the $1 / 160$ th acre plots to $5 \cdot 8 \%$ at the $1 / 40$ th acre plots. Further increase in size up to $1 / 10$ th acre only reduces this quantity to $4.6 \%$. Now, since the larger the area, the greater the difficulty in obtaining an " apparently uniform " area of soil, it follows that little is to be gained by increasing the size of plot for yield trials above $1 / 40$ th of an acre.

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Fig. 3.-Actual and Theoretical Curves of the Standard Deviation of Plots of Various Sizes.
N.B.-The theoretical curve is obtained by the division of the S.D. of the $1 / 160$ th acre plots by the square root of the number of the original number of small plots combined in each grouping.

## Optimum Shape of Plot.

It is generally considered that a long narrow plot is more desirable for field-scale work than a short square plot, and the following table tends to establish this belief.

Table 5.-Standard Deriation of Plots of Various Shapes.

| Size of <br> Mlot | No. of <br> Plots | Dimensions | Standard \% <br> Deviation |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $1 / 40$ th ac. | - | 40 | - | $60 \times 40 \mathrm{lks}$. | - |
| $1 / 40$ th, | - | 32 | - | $20 \times 120,$, | - |
| $1 / 20$ th, | - | 20 | - | $80 \times 60$, | - |
| $1 / 20$ th, | - | 16 | - | $20 \times 120$, | - |

It is important to note that on account of the gradual increase in yield from east to west, plots with their axis in a north to south direction cannot be used in the above comparison.

## Optimum Number of Replications desirable.

Having determined the size and shape most desirable from a practical standpoint, it was necessary to find the number of replications required for a working minimum of error. The S.D. was then calculated for two scattered $1 / 20$ th acre plots, four scattered $1 / 40$ th acre plots, etc. Maximum scattering was obtained by entering the yields of the various sized plots on slips of paper, which were later drawn from a bowl, and thus the various sets of pairs, fours, eights, etc., were made up.

Table 6.-Standard Deviation of $1 / 10 t_{h}$ acre plots obtained by random grouping of various numbers of units.

| No. of Units <br> in $1 / 10$ ac. plot | No. of <br> observations | Standard Deviation <br> $\% / \%$ |  |  |
| :---: | :---: | :---: | :---: | :---: |
| 1 | - | 1 | - | $4 \cdot 6 \%$ |
| 2 | - | 2 | - | $4 \cdot 0$ |
| 4 | - | 4 | - | $3 \cdot 18$ |
| 8 | - | 8 | - | $2 \cdot 16$ |
| 16 | - | 16 | - | $2 \cdot 3$ |

N.B.-Only a low reliability can be placed on the figure 46 , due to the small number of results.

From this it would appear that a greater number of replications than four or five is not warranted, as the small increase in accuracy so obtained would entail a great amount of extra work.


Fig. 4.-Relation betrecen the Standard Deviation and the Number of Replications.
(Actual and Theoretical).
N.B.-The theoretical value is obtained by the division of the S.D. of $1 / 10$ th acre plots by the square root of the number of tunits into which it was divided.

## Conclusions.

While the small number of observations necessarily detracts from the accuracy of some of the restilts, the following conclusions seem to be justified, supporting, as they do. most of the previous work overseas.
(1) That in this field experiment, there are two types of error(a) casual, due to small chance errors in harvesting technique, uneven seeding, manuring, hare-tracks, etc. These may be so gradual as to be inappreciable to the eye.
(b) more regular errors, due to marked soil variations, climate, etc.
(2) That the casual error attaching to a single plot decreases with the increasing size of plot, but the more systematic error of soil variation becomes more important as the plot increases in size.
(3) The optimum size for field trials for cereals under conditions such as these, is $1 / 40$ th acre.
(4) That there would appear to be grounds for the belief that a long narrow plot is the more desirable for field trials.
(5) That the error attaching to a $1 / 40$ th acre plot is diminished to a working ninimum by a replication of five times in any one series.
It is absolutely essential that these results be applied with caution. They are only of value for the conditions which prevailed during the period of the experiment, on the particular soil on which the experiment was conducted. Thus in the first place they will apply only to areas of crop in which the cye is unable to detect any serious lack of uniformity. If a field, used for yield trials, contained areas in which the crop was locally affected owing to disease, extra-heavy rain or some other exceptional circumstance, there would be no reason for expecting that the statistical results obtained in the Werribee work would hold good in such an area.

In the second place, with different climatic conditions the results might be different, but the marked similarity between the results at Werribee and at Rothansted suggests that this is not likely to be a very serious source of trouble.

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